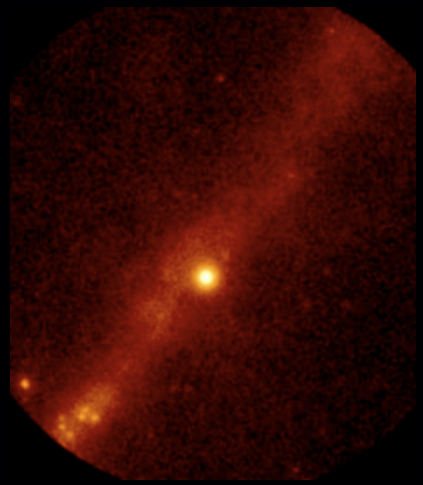
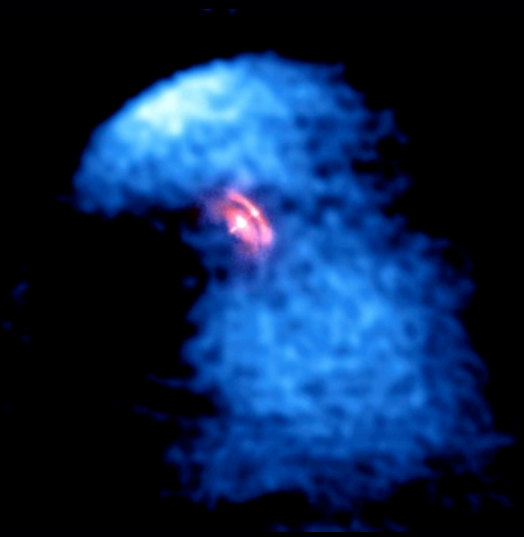
Pulsar wind nebulae in X-ray, TeV, and in between!

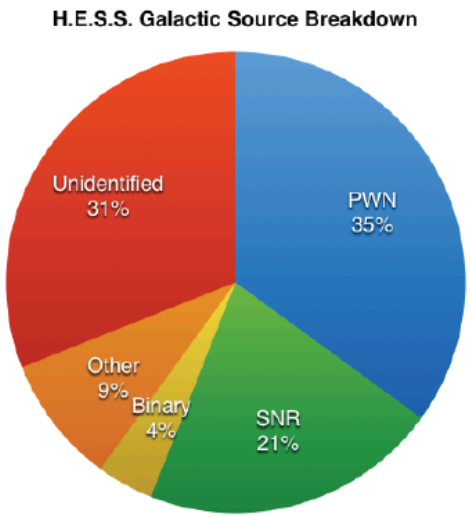
Oleg Kargaltsev (George Washington University)



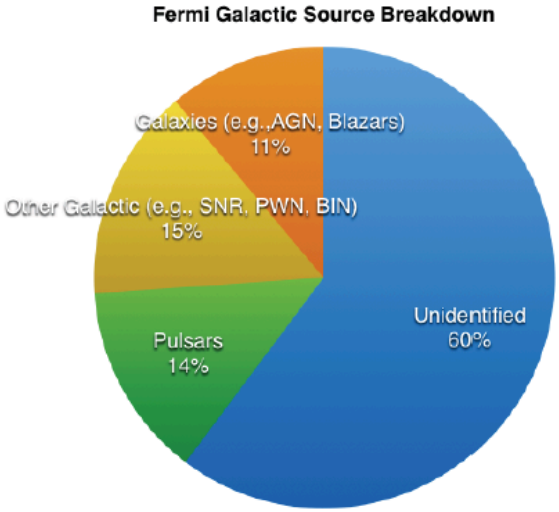


Future Space-based Gamma-ray Observatories
NASA/GSFC February 5, 2015

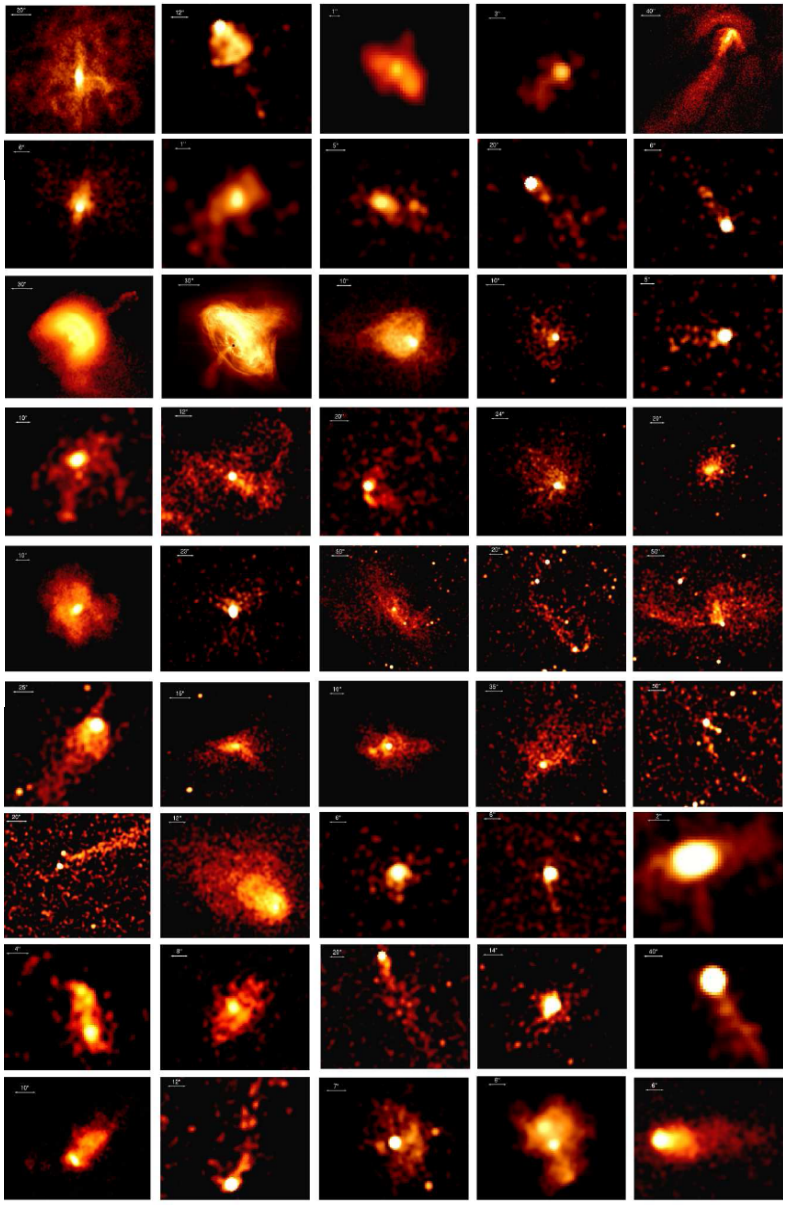
PWNe in X-rays and Gamma-rays



HESS collaboration



Based on 3FGL catalog
(made by Jeremy Hare)



Observations in soft gamma-rays can:

- Constrain spectral slope, break and maximum energy of particles from synchrotron emission - link to acceleration process
- Constrain transport mechanisms (diffusion vs. bulk flow)
- Constrain magnetization and composition
- Constrain magnetic fields via cooling (spectral cut-off) evolution as a function of distance from the pulsar
- PWNe (pulsar winds) are very similar to AGNs, GRBs, microquasars!

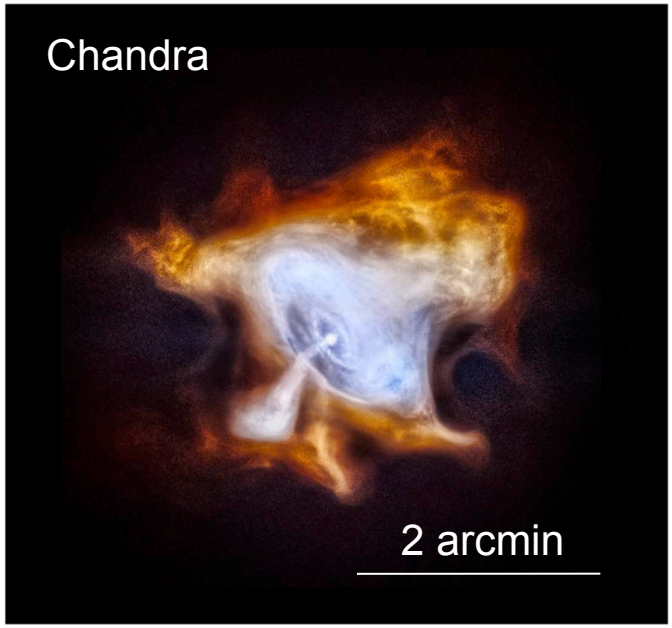
Objects to study in MeV should be

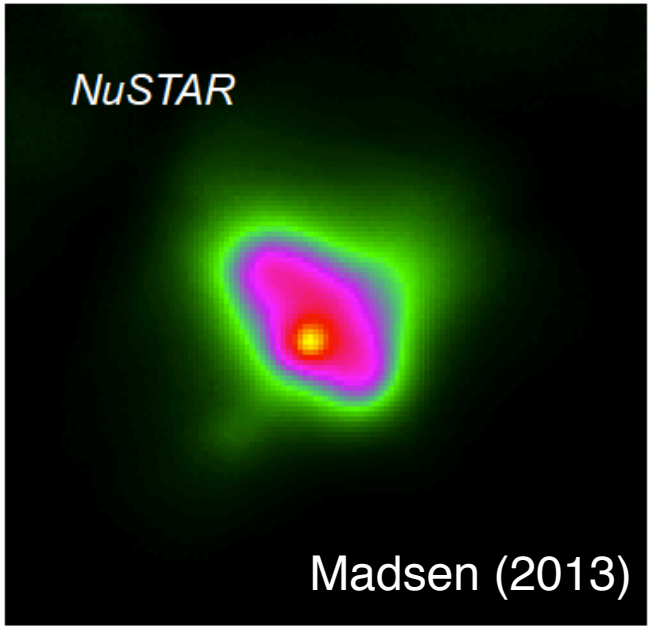
- Big on the sky
- Bright
- Represent the diversity of PWN population (in terms of age, Edot, PWN morphology,...)
- Have something special (e.g., flares in Crab)

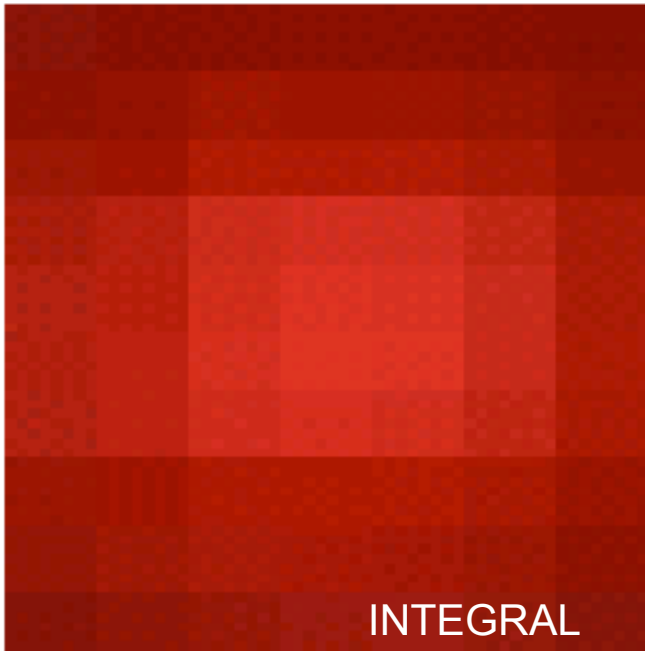
Some interesting things to look for?

- Can Vela or MSH 15-52 PWN have flares in MeV?
- Can the delayed effects of Crab GeV flares be seen in MeV ?

Crab PWN in soft X-rays and higher energies:







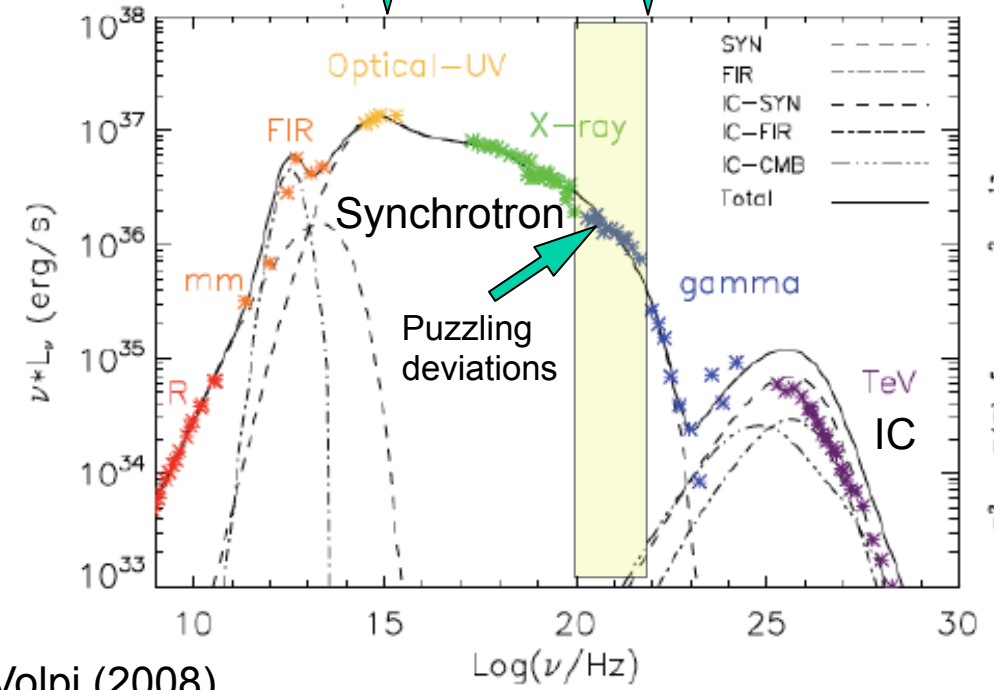
Multiwavelength spectrum of the Crab PWN

Break

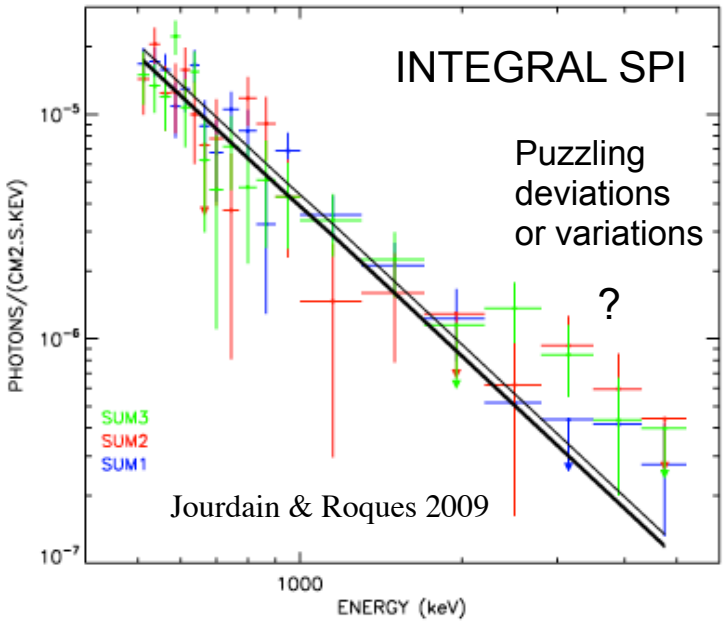
Cut-off

$$E_{\rm syn} \sim 4(E_e/100\,{\rm TeV})^2(B/10^{-5}\,{\rm G})\ {\rm keV},$$

$$E_{\rm ICS} \sim 1(E_e/20\,{\rm TeV})^2(\epsilon/6\times10^{-4}\,{\rm eV})\ {\rm TeV},$$



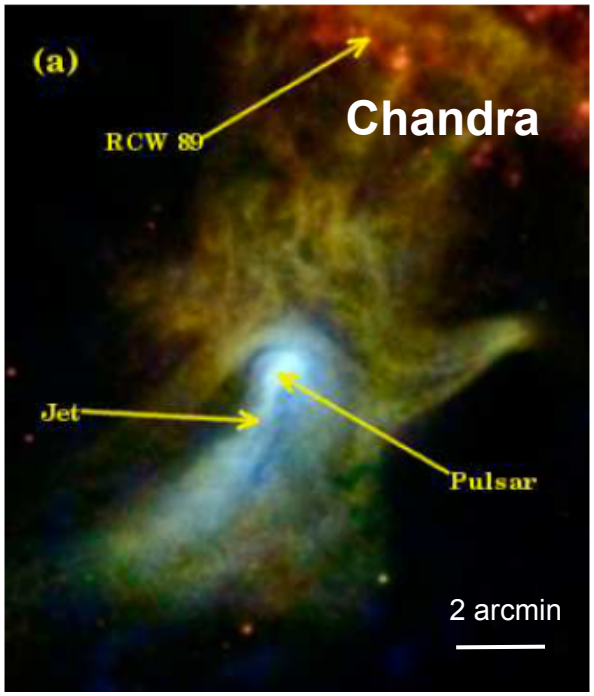
Volpi (2008)

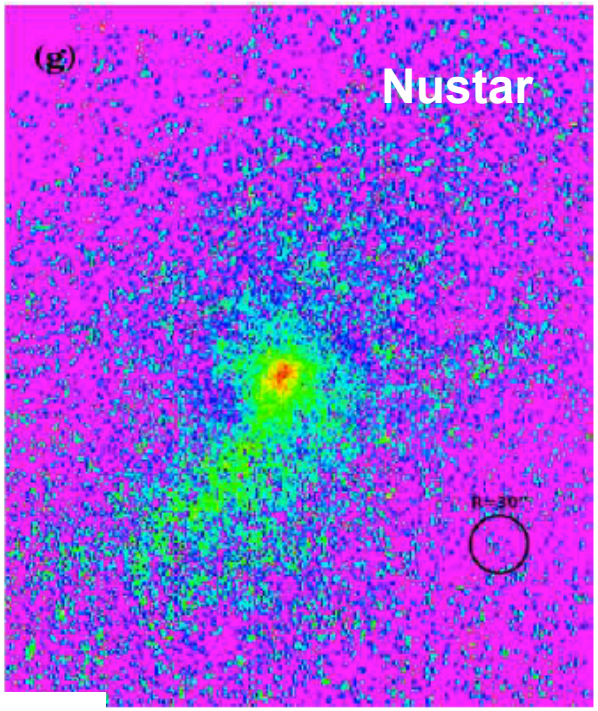


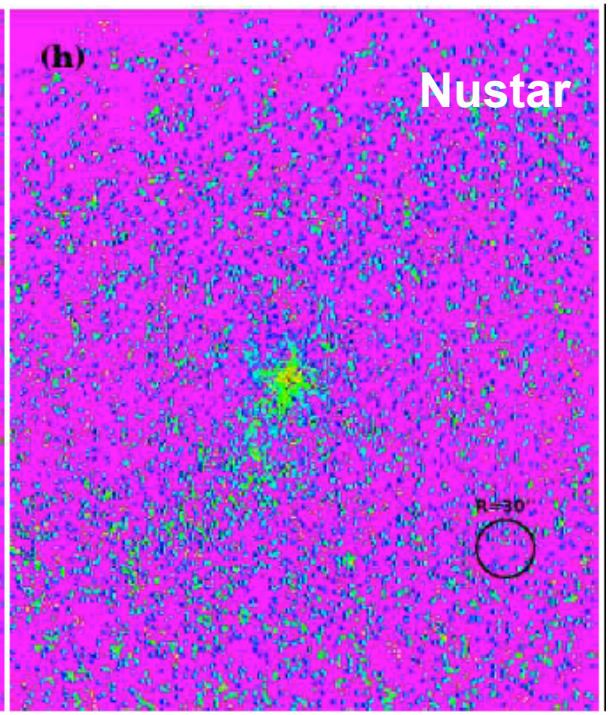
References for the reported data are as follows: radio data are from Baars & Hartsuijker (1972); the mm data are from Mezger et al. (1986) and Bandiera et al. (2002); the infrared points are from IRAS in the far to mid-infrared (Strom & Greidanus 1992) and from ISO in the mid to near infrared range (Douvion et al. 2001); optical is from Véron-cetty & Woltjer (1993) and UV from Hennessy et al. (1992). Points in the range between soft X and gamma-rays are taken from Kuiper et al. (2001), who compiled data from BeppoSAX, COMPTEL and EGRET. In the TeV band, we plot the data from MAGIC (Albert et al. 2008) and HEGRA (Aharonian et al. 2004).

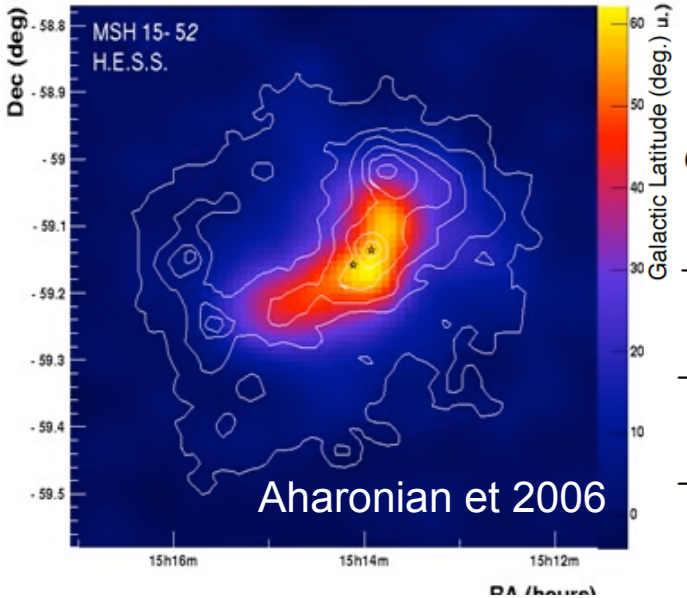
MSH 15-52

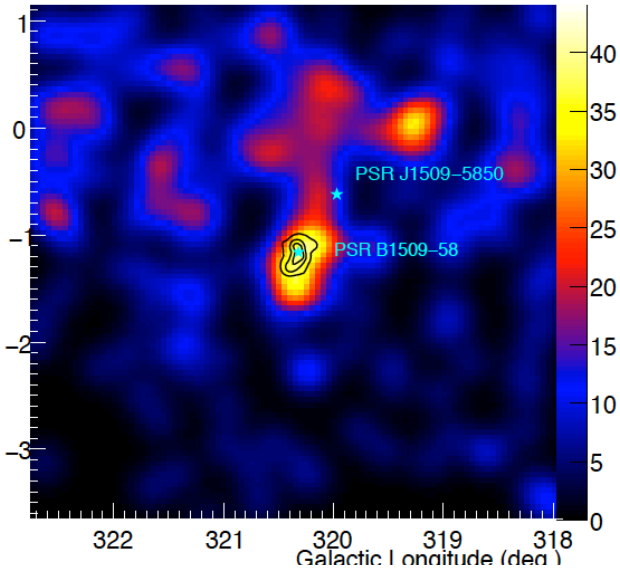
An et al. 2014

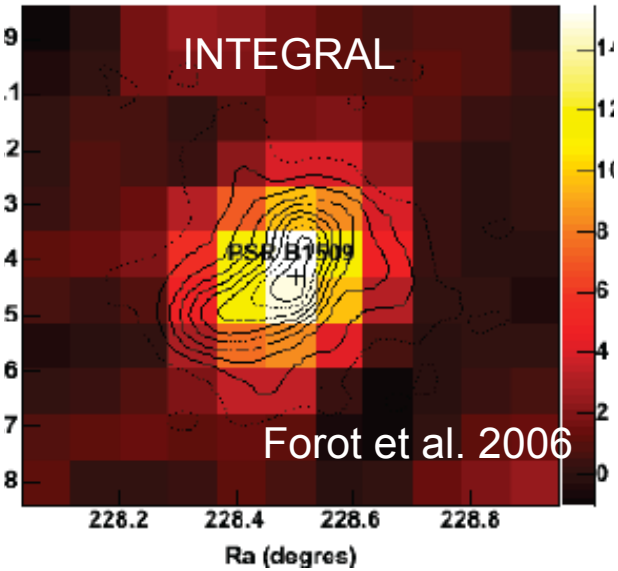






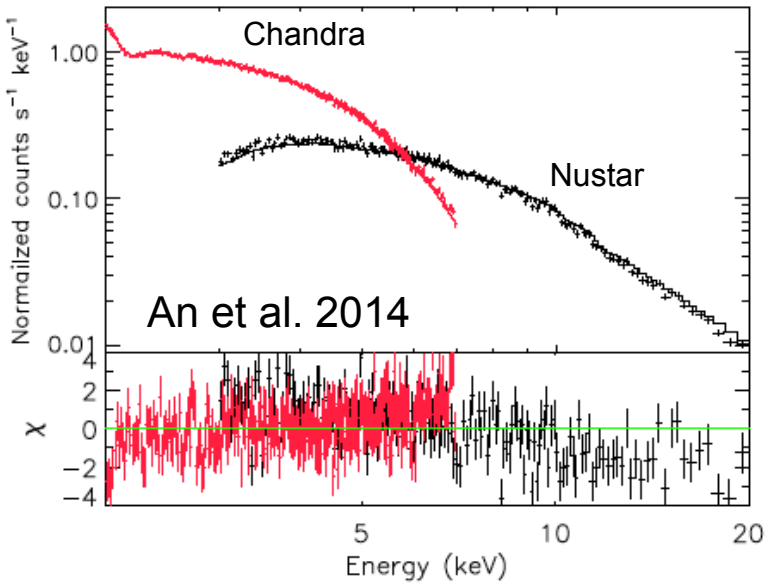


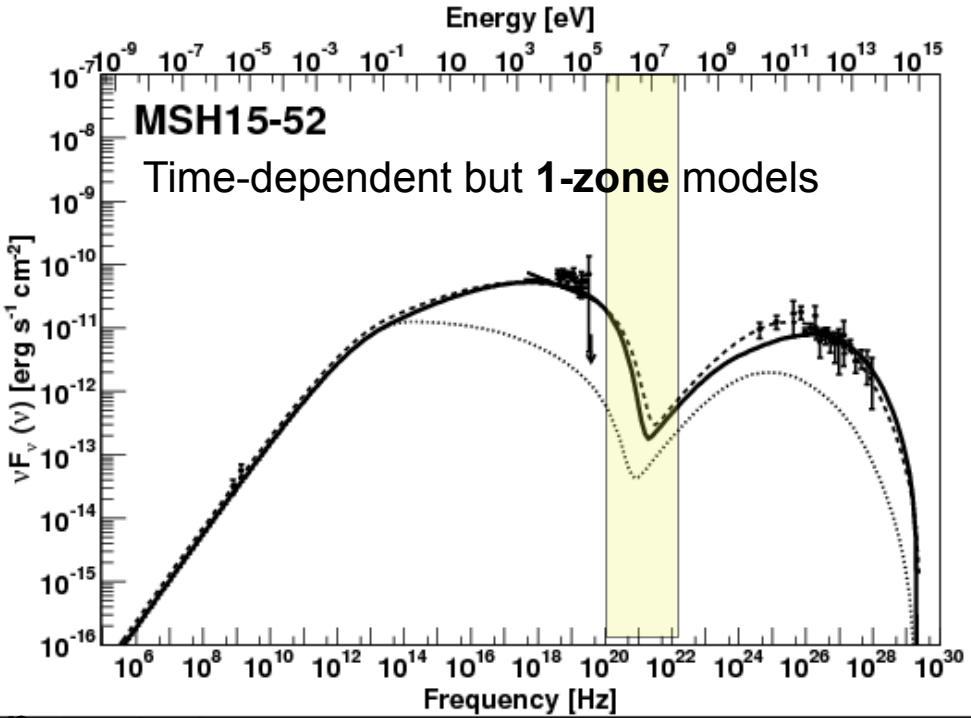




Spectrum of MSH 15-52

Possible very mild **break** around 6 keV, confirmation needed!





Gelfand et al. (2009), ... **Torres et al. (2014)**

Where is the cooling break and synchrotron cut-off?

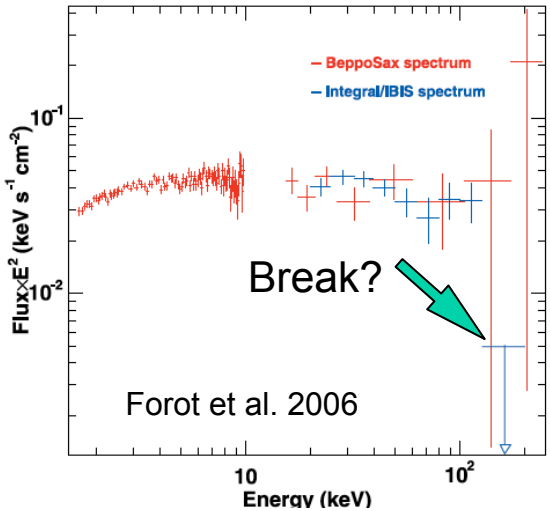
Cooling times related to cooling break energy:

$$\tau_X \approx 1.2\, B_{-5}^{-3/2} (E_{\rm syn}/1\ {\rm keV})^{-1/2}\ {\rm kyr}$$

$$\tau_\gamma \approx 100(1+0.144 B_{-6}^2)^{-1} (E_{ICS}/1{\rm TeV})^{-1/2}\ {\rm kyr}$$

Knowing residence time τ and break energy E constrains B.
Measuring synchrotron cut-off energy constrains combination of maximum electron energy and B. IC provides additional constrains.

Connection to the particle transport models (diffusion vs. bulk flow), enabling multi-zone models.



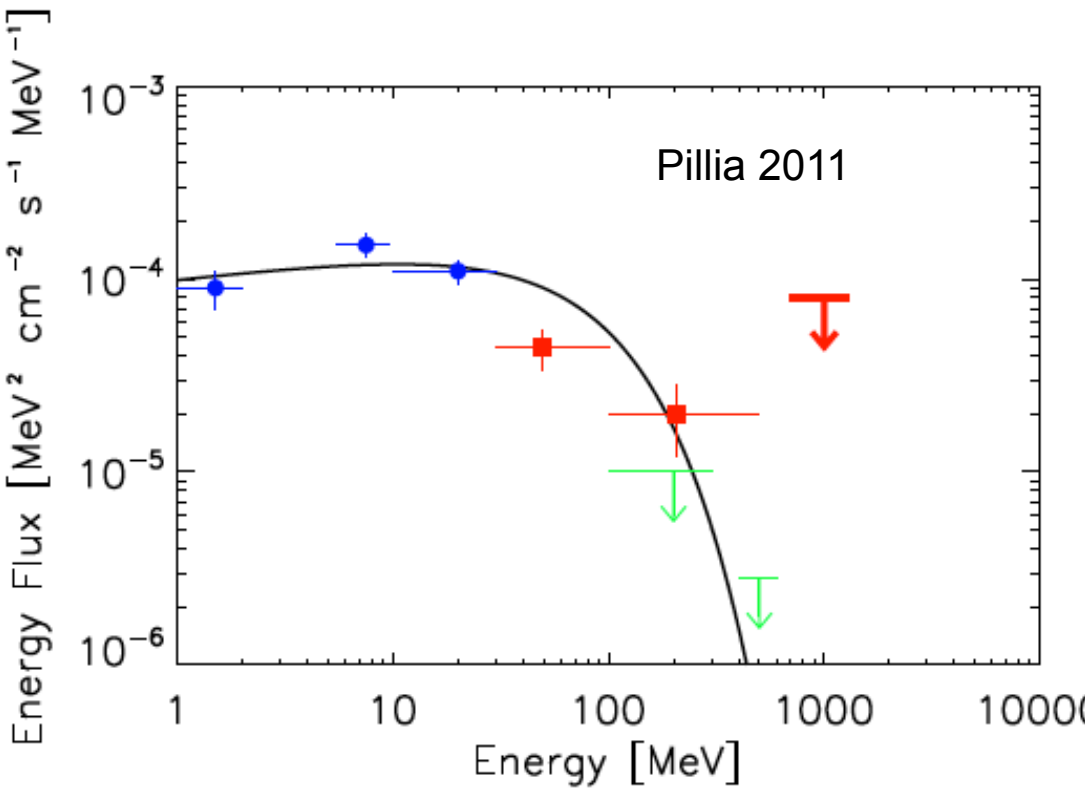
Not talking about pulsars today but..

B1509-58 in MSH 15-52

An interesting type of

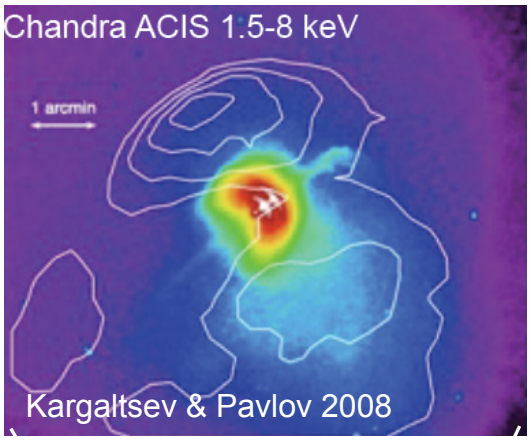
soft-gamma ray pulsar

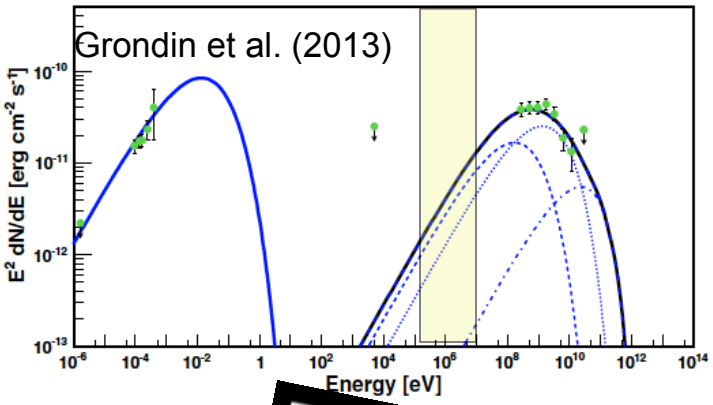
with cut-off in MeV range!

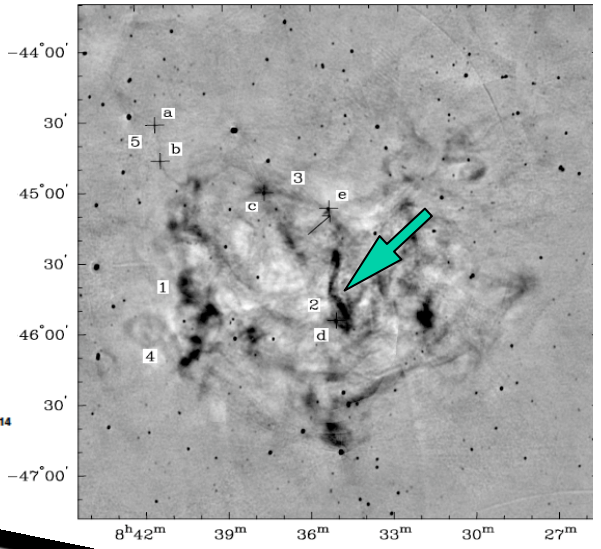


Would be good to look for annihilation lines from positrons...

Vela PWN and Vela X







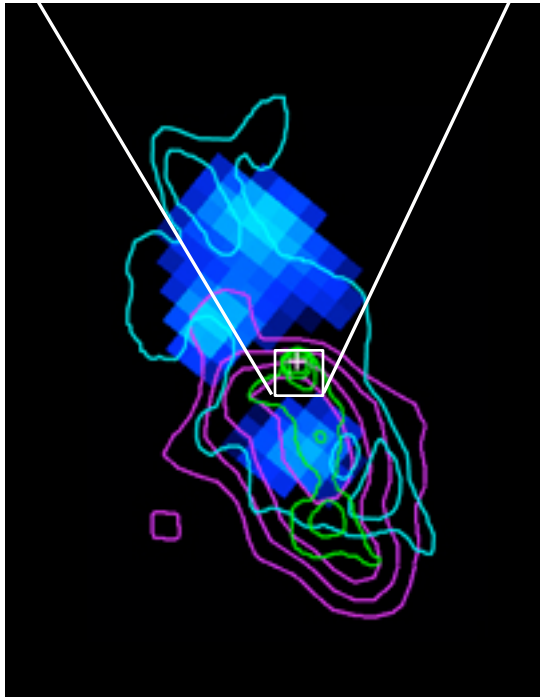
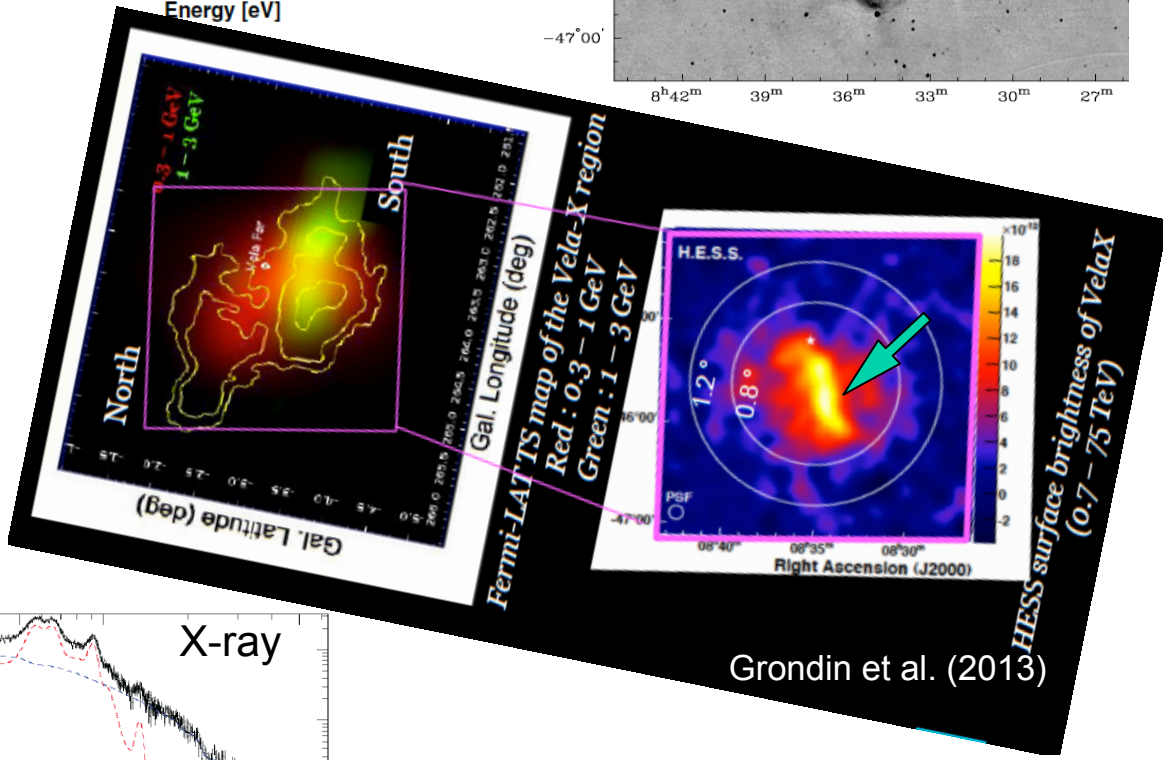
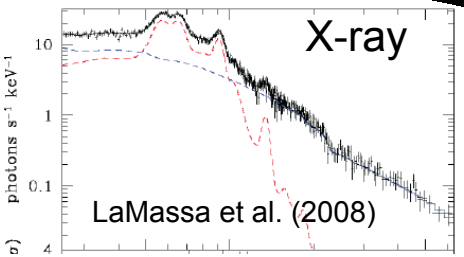


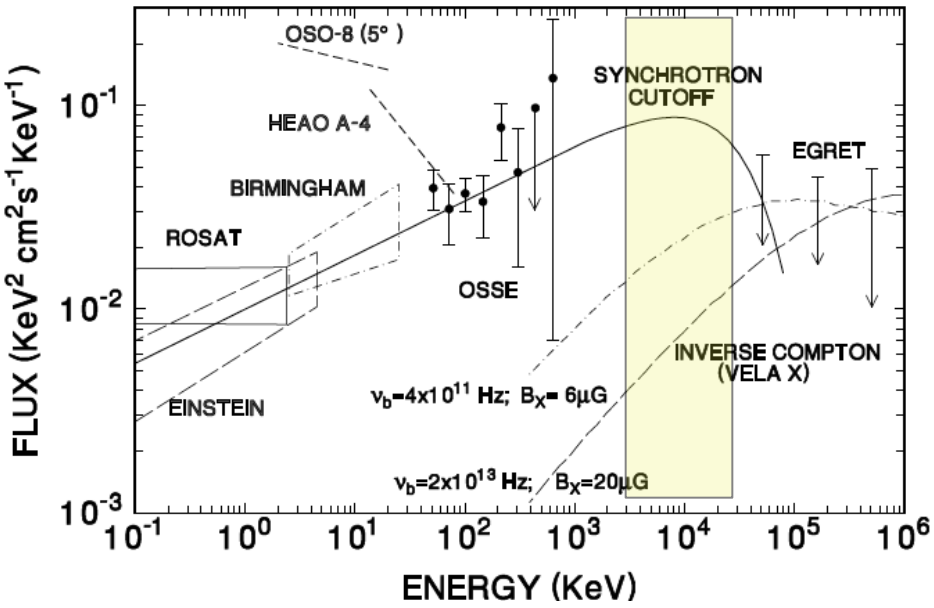
Image: INTEGRAL, 18-40 keV
(Mattana et al. 2011)

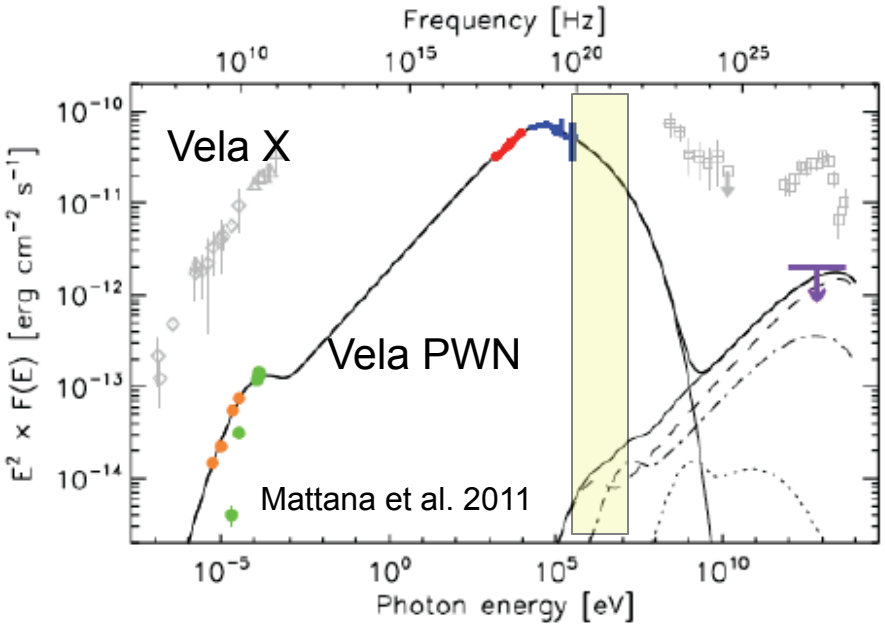


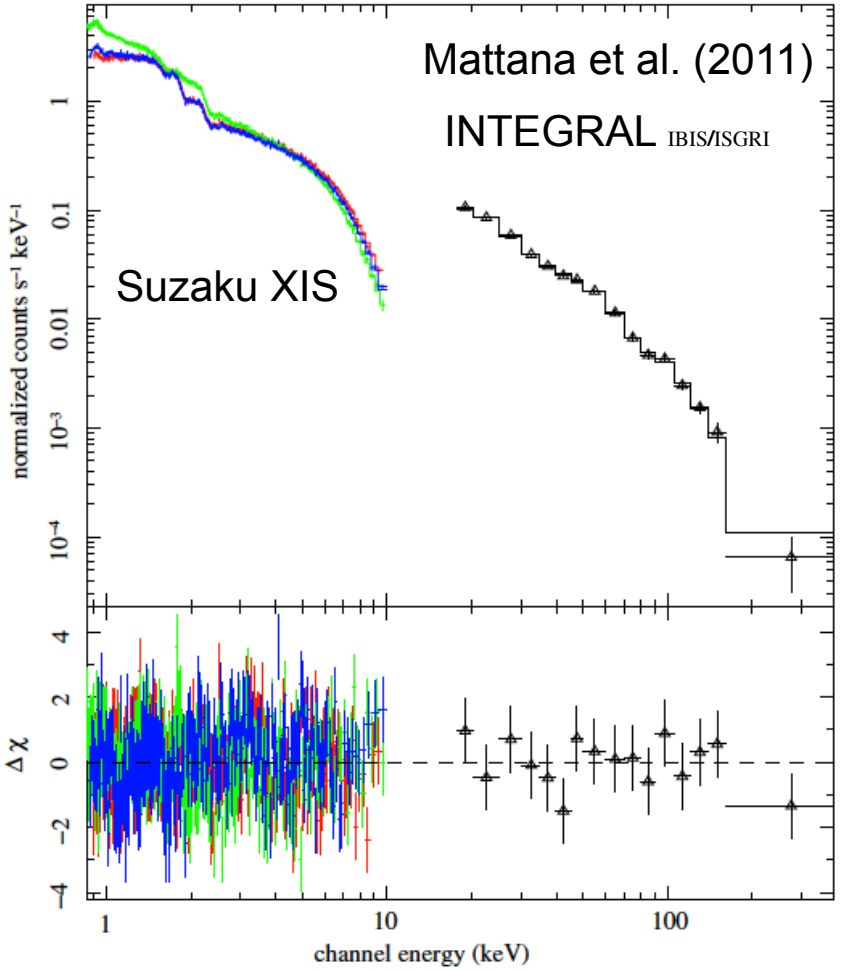


Vela PWN spectrum

de Jager (1997)







Where is the synchrotron cut-off?

$$E_{\rm syn} \sim 4(E_e/100\,{\rm TeV})^2(B/10^{-5}\,{\rm G})\ {\rm keV},$$

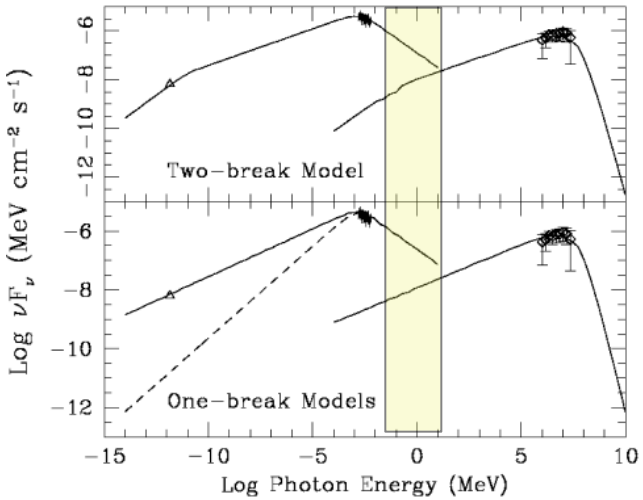
$$E_{\rm ICS} \sim 1(E_e/20\,{\rm TeV})^2(\epsilon/6\times10^{-4}\,{\rm eV})\ {\rm TeV},$$

Need arcminute resolution and good sensitivity in MeV range!

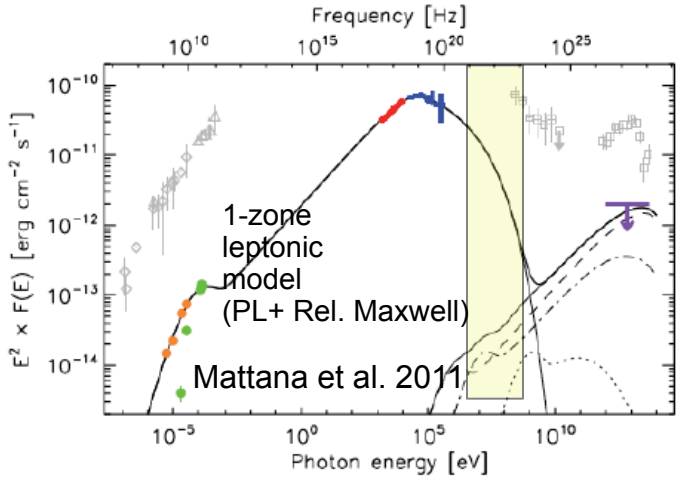
Discriminating between pulsar-wind models:

1-Zone Synchrotron + IC on CMB model for Vela X cocoon (from LaMassa et al. 2008) - different SEDs of the injected electron assumed on top and bottom.

LaMassa et al. (2008)



Leptonic vs. lepto-hadronic models



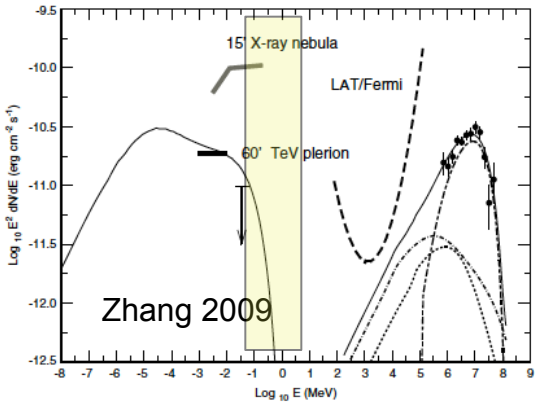
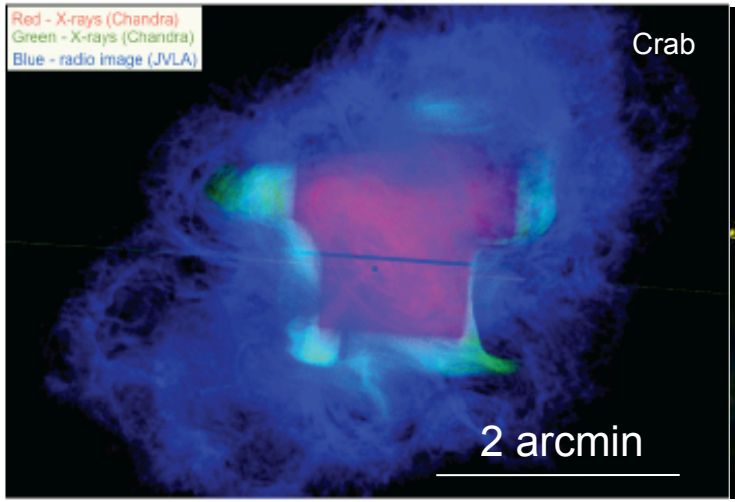
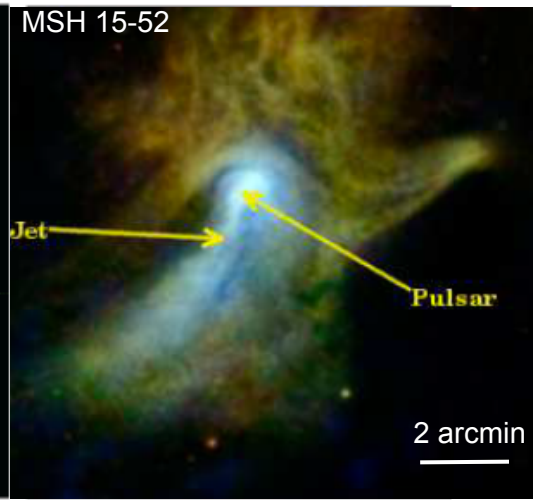


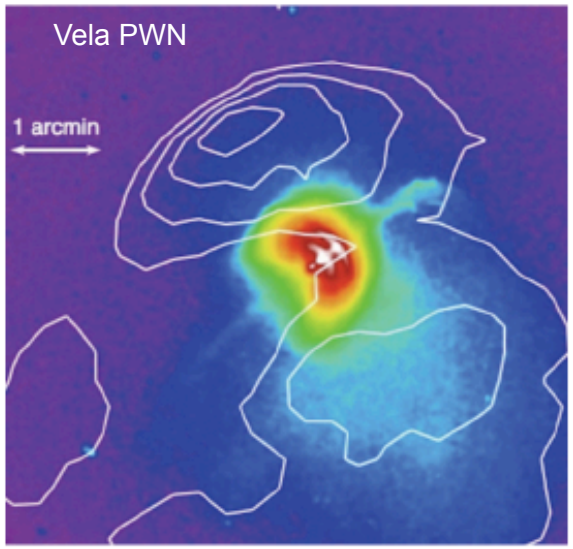
Figure 2. Comparison of predicted spectra in the leptonic-hadronic model with r Vela X. The basic model parameters are described in

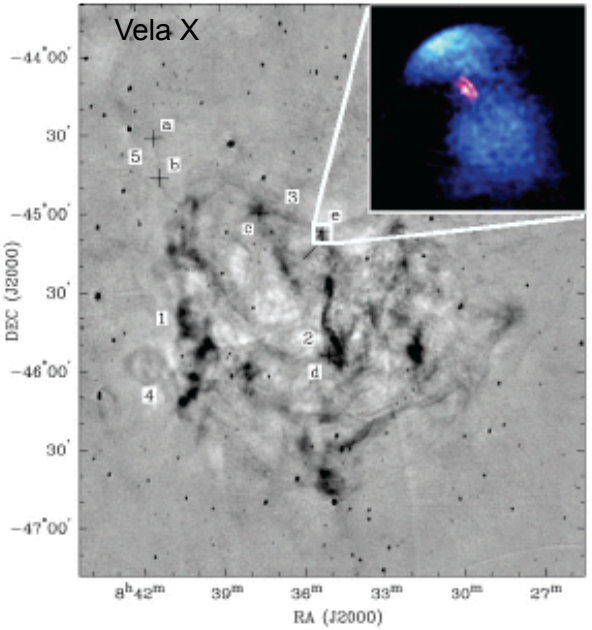
Possible importance of hadronic processes in PWNe:
Cheng et al. (1990), Atoyan & Aharonian (1996), Bednarek & Protheroe (1997), Amato, Guetta & Blasi (2003), Bednarek & Bartosik (2003).

Crab and Vela PWN angular scales are comparable : need <1 arcminute resolution in MeV!









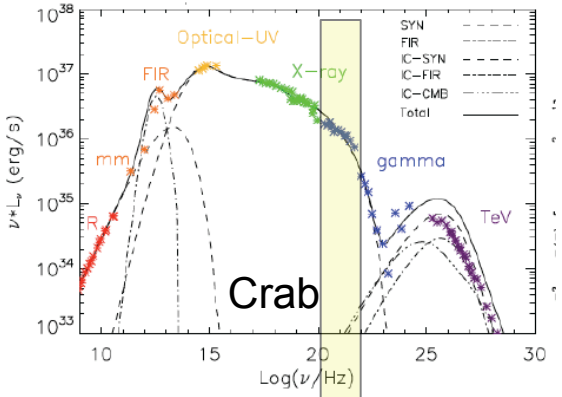
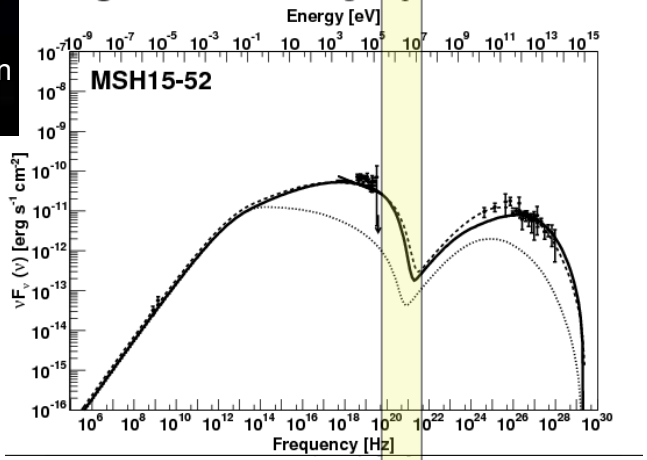
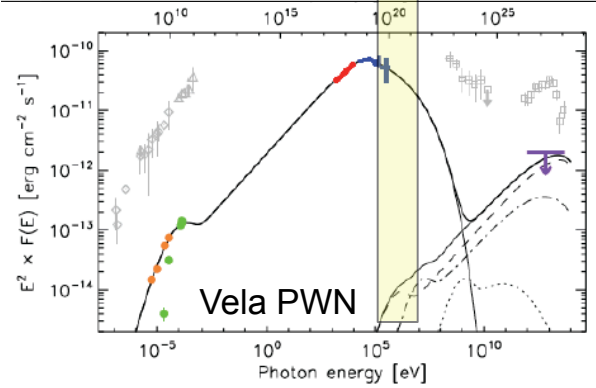


Fig. 13 Multiwavelength spectra of the Crab





Mission requirements

- Sensitivity <0.1% of Crab
- Resolution <1 arcmin
- energy range 100 keV - 100 MeV (can be narrower); can be narrower if helps with resolution
- Energy resolution can be a trade-off